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(56) Documents Cited
US 5418823 A US 5329561 A US 5225148 A
US 5062298 A

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(54) Thickness measurement

(57) Apparatus for measuring the thickness of a non-magnetic coating 14 and a magnetically susceptible substrate 12 comprises, in combination, an ultrasonic transmitter and receiver 2,3 and timing means arranged to ascertain the transit time of an ultrasonic pulse through the coating and substrate, a magnet 4 one pole of which faces the coating surface, a magnetic field sensor (e.g. a Hall effect device 5) between the pole of the magnet and the coating surface and a processor arranged to ascertain from at least the output of the magnetic field sensor the coating thickness and from this and from the transit time of the ultrasonic pulse the thickness of the substrate. Preferably, the apparatus comprises means for displaying both calculated thicknesses.

Fig3

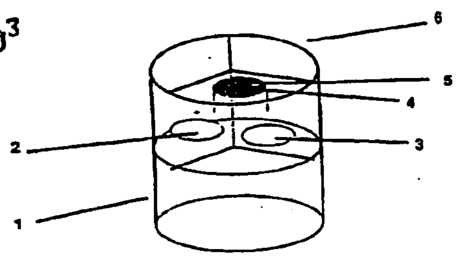
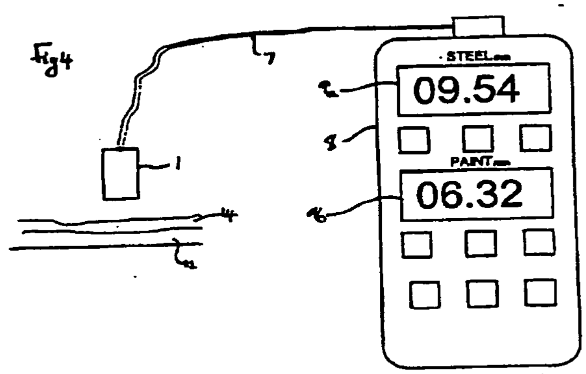


Fig4



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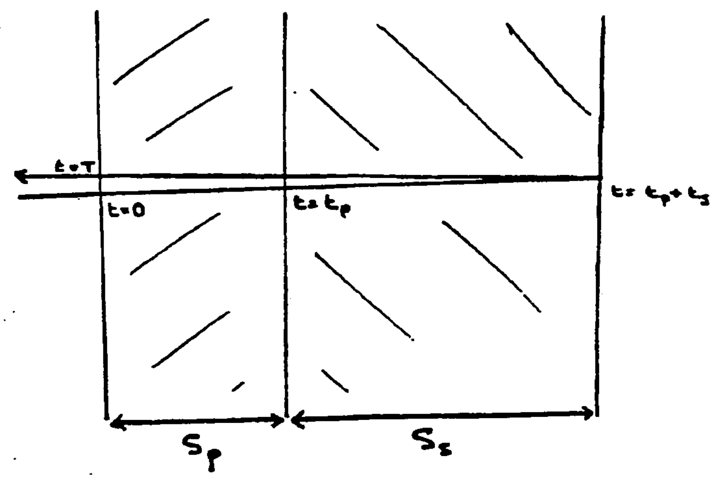
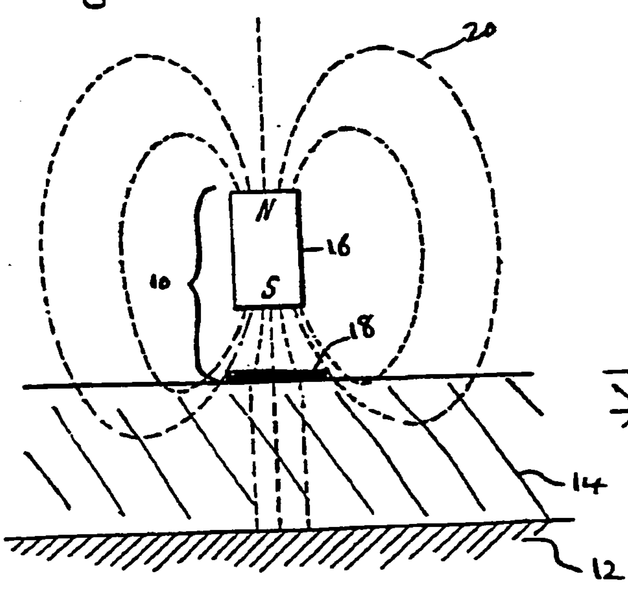


Fig 1

Fig 2a



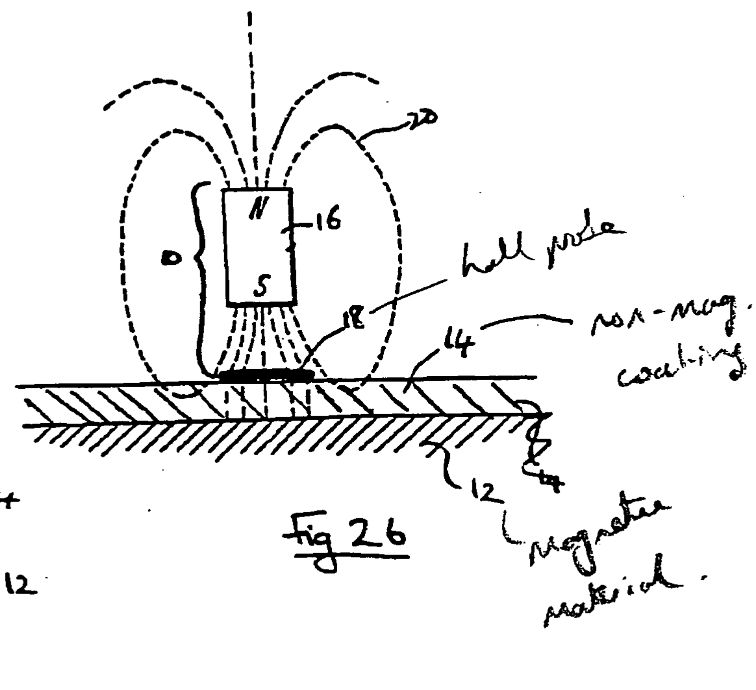


Fig 2b

Fig3

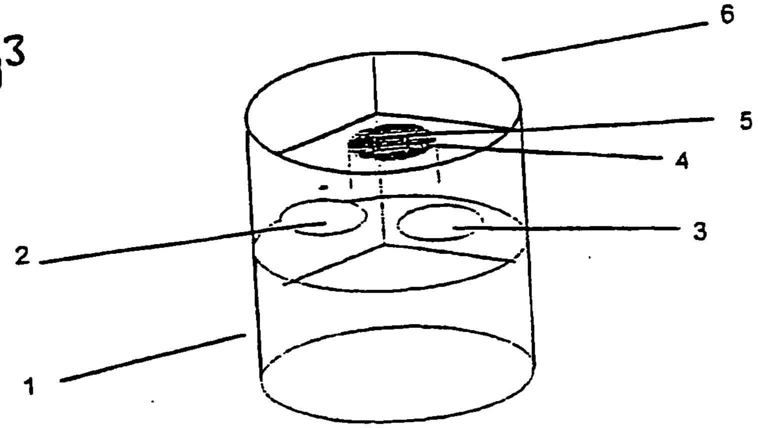


Fig4

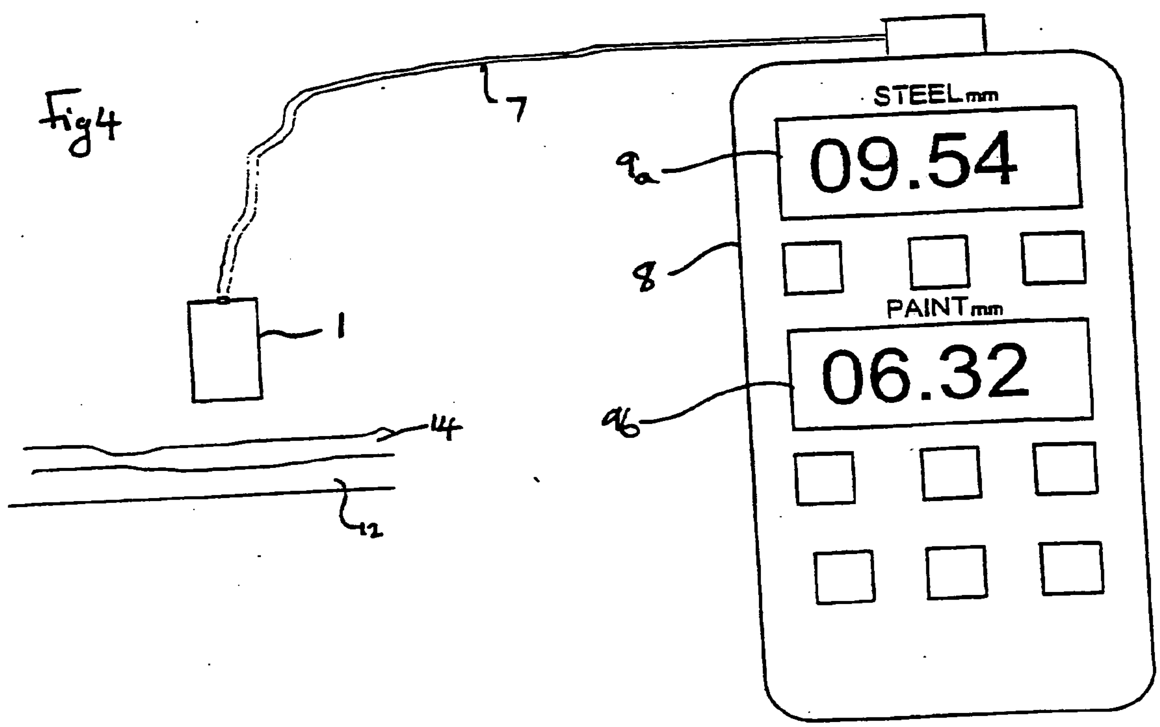


Fig 5

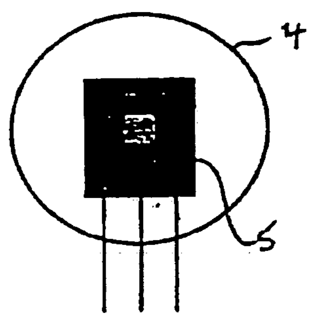


Fig 6

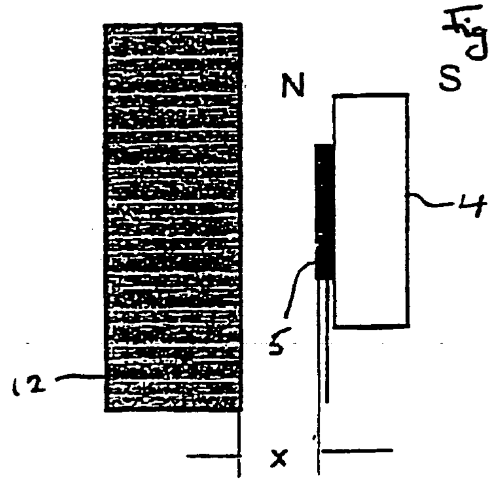
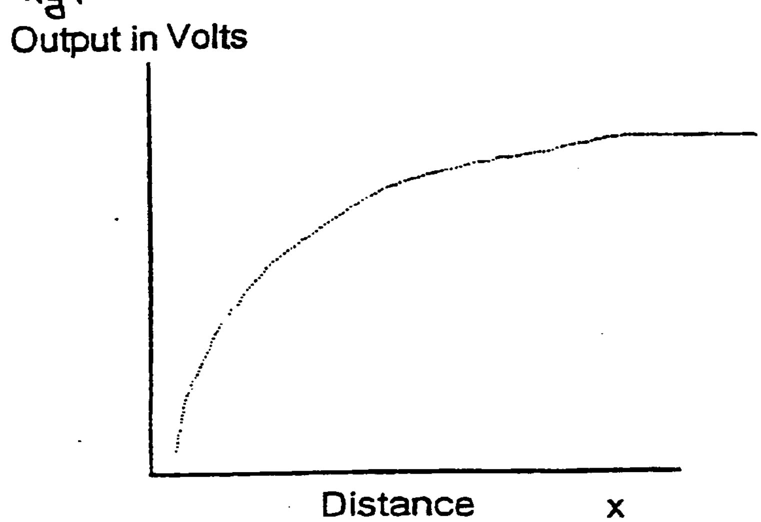


Fig 7



THICKNESS MEASUREMENT

The present invention relates to an apparatus for, and method of, ascertaining the thickness of layers in a structure comprising a non-magnetic surface coating and a magnetically susceptible substrate. It is particularly, but not exclusively, concerned with measuring the thickness of a paint layer and of an underlying ferrous layer.

Ultrasonic thickness measurement devices are known *per se*, for example from GB 2282226. The devices operate by sending a brief ultrasonic pulse through the material, and noting the time of return of reflected pulses. Generally speaking, a first portion of the pulse will be reflected from the front surface of the specimen in question, and a second portion of the pulse will be reflected from the rear surface.

Ultrasonic probes can also be used to investigate the internal structure of the material, since a reflection will be produced by internal flaws and defects.

Such devices are not particularly suitable for measuring the thickness of composite specimens, such as a steel plate with a surface coating of paint. This is because the speed of sound in the two components is different. Thus, as illustrated schematically in Figure 1, the total time T for the pulse to pass from the front surface to the rear surface and back is given by the sum of the journey times;

$$T = 2(t_p + t_s)$$

If the thicknesses of the paint and steel layers are s_p and s_s respectively, and the speeds of sound in the two layers are v_p and v_s respectively, then the above equation can be substituted to read;

$$T = 2(s_p/v_p + s_s/v_s)$$

In this equation, the values T, v_p and v_s are known, and this leaves a single equation with two unknowns. Hence, the solution cannot be found using the ultrasound apparatus alone.

GB 2271641 discloses a coating thickness gauge suitable for a non-conductive coating on a conductive, non-ferrous substrate or a non-ferrous coating on a ferrous substrate. It comprises a Hall effect sensor placed between the coating surface and a permanent magnet. It is unable to measure the thickness of the underlying substrate.

The present invention provides an apparatus for measuring the thickness of a non-magnetic coating and a magnetically susceptible substrate comprising, in combination;

an ultrasonic transmitter and receiver and timing means arranged to ascertain the transit time of an ultrasonic pulse through the coating and substrate;

a magnet one pole of which faces the coating surface;

a magnetic field sensor between the pole of the magnet and the coating surface; and

a processor arranged to ascertain from at least the output of the magnetic field sensor the coating thickness and from this and from the transit time of the ultrasonic pulse the thickness of the substrate.

Thus, the thickness of the coating is measured by magnetically based means. This provides the additional information necessary to ascertain the substrate thickness.

It is preferred, for reasons of accuracy, that the magnetic sensor is physically attached to the pole of the magnet. A suitable magnetic field sensor is a Hall effect device.

The output of a Hall effect device is distinctly non-linear and therefore the present invention preferably includes a linearizing means for linearizing the output. This linearizing means can comprise a look up table, or substitution into a suitable mathematical model such as a polynomial approximation.

Preferably, the thickness of the magnet is greater than 6mm, more preferably greater than 10mm, and particularly preferably greater than 22mm. This is because the inventor has found that more accurate results can be obtained so long as the magnet is more than twice the thickness of the underlying substrate. The present invention is particularly applicable to measuring the thickness of painted steel hull of a ship, which hulls normally have a thickness between 3 and 11mm.

Preferably, there is a distinct transmitter and receiver of ultrasonic pulses. However, it is possible for the same transducer device to provide both functions.

Preferably, the apparatus has means for displaying both calculated thicknesses, although this is not necessary and particular embodiments may be adapted to display only one such thickness.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying figures in which;

Figure 1 is a schematic representation of the ultrasound to measure the thickness of a two layer specimen;

Figures 2a and 2b are schematic representations of thickness measurement using magnetic susceptibility;

Figure 3 is a partially cut away perspective view of the sensor according to the present invention;

Figure 4 is a representation of a system including the sensor of Figure 3;

Figure 5 is a front view of the magnetic sensor of Figure 3;

Figure 6 is a view from the side of Figure 5; and

Figure 7 is a graph showing the dependence of the output of the magnetic sensor of Figure 6 on the distance between it and a magnetically susceptible body.

Figure 1 has been discussed above, and will not be discussed further.

Figures 2a and 2b show schematically how the distance between a sensor 10 and a magnetically susceptible body 12 can be measured. In each figure, the magnetically susceptible body 12 is covered with a coating 14 which is thicker in Figure 2a than in Figure 2b.

The sensor consists of a magnet 16 and a Hall effect sensor 18. They are held in a fixed relationship by a housing (not shown), by which one pole (in this case the South pole) of the magnet faces the surface of the coating 14, and the Hall effect sensor 18 is placed against that surface.

The magnet 16 can be a permanent magnet or an electromagnet. An electromagnet would have the advantage of a variable and reversible magnetic field. Hence, a greater strength field could be used for thicker

coating layers, or a high powered pulsed field for very large coating thicknesses. Pulsing of the field would also conserve electrical power. A reversible field would eliminate error caused by prior magnetism of the substrate, by averaging the results obtained.

Lines of force 20 emanate from the poles of the magnet 16 in a known fashion. As can be seen from Figures 2a and 2b, the closer the magnet is to the magnetically susceptible substrate 12, the more lines of force intercept that surface and are hence drawn thereto. Thus, the lesser the distance, and thus the thinner the coating 14, the more lines of force 20 pass through the Hall effect sensor 18. Thus, the magnetic field detected by that sensor is correspondingly greater and its electrical output responds correspondingly.

Figure 3 shows a suitable arrangement for the sensor according to the present invention. The sensor body 1 contains an ultrasonic transmitter 2 and an ultrasonic receiver 3. Between the ultrasonic transducers and the front face 6 of the sensor, there is a magnet 4 one pole of which faces the front face 6. Affixed to that pole of the magnet 4 is a Hall effect device 5. The Hall effect device is conveniently in integrated circuit form.

Figure 4 shows the sensor 1 of Figure 3 integrated into a system. The sensor is connected via cable 7 to a processor unit 8 which has digital read outs 9a and 9b of the calculated thicknesses of the underlying magnetically susceptible layer and non-magnetic coating layer respectively.

Figures 5 and 6 show the magnet 4 and Hall effect sensor 5 in more detail. It can be seen that the Hall effect sensor 5 is affixed to the front surface of a disc-shaped permanent magnet 4. The combination is placed before the magnetically susceptible body 12 with a gap of distance x therebetween.

It is not, however, essential for the magnet to be directly behind the Hall effect sensor, as long as the sensor is within the magnetic field.

Figure 7 shows an experimentally obtained graph of the output of an ic-based Hall effect sensor 5 for a range of values of x. On the graph, x varies from 0 to 9mm and hence it can be seen at detectable changes in the output voltage are obtained with changes in x up to 9mm. This is sufficient for most paint layers on steel or other ferrous substrates.

In use, the sensor 1 is placed against the paint surface 14 and the processing unit 8 activated. The magnet 14 operates permanently, and therefore a reading can be taken immediately from the Hall effect sensor 5. The ultrasonic transmitter 2 emits a 5 MHz pulse which travels forward through the sensor, past the magnet 4 and Hall effect sensor 5 and towards the specimen 12, 14. Part of the pulse is reflected from the front surface of the paint layer 14 and is detected by the ultrasonic receiver 3 on its return journey. The remainder of the pulse passes through the paint layer 14 and steel layer 12, is reflected from the rear surface of the steel layer 12, and is also detected on its return trip by the ultrasonic receiver 3.

A timing device within the processor 8 is activated on detection of the first pulse and halted on detection of the second pulse. Simple subtraction shows that this time gap is equal to the transit time of the pulse through the paint and steel layers.

The processor calculates from the output of the Hall effect sensor 5 the distance between the sensor and the near face of the steel layer 12. In this embodiment, this is done by consulting a look-up table which is based on the date of Figure 7. It could, however, be done by operation of a suitable algorithm model.

Having calculated the paint thickness, the processor can calculate the

transit time through the paint layer using the (known) speed of sound in paint, and hence arrive at the transit time element relating to the steel layer. Thus, the thickness of the steel layer can be ascertained.

Both figures are then displayed in the output windows 9a and 9b.

It will be appreciated by those skilled in the art, that the above-described embodiment is purely illustrative and that many variations are possible whilst remaining within the scope of this invention. For example, an electromagnet could provide a variable field strength so that during a reading the output of the Hall effect device was maintained at a constant value. Then, the induction current of the electromagnet would (together with the Hall effect sensor output) give the necessary information to ascertain the coating thickness. Embodiments could also be prepared with a storage means to log readings obtained, for future analysis. Alternatively, the reading could be transmitted back to a central station. This would allow remote automatic operation, for example in an inhospitable or inaccessible region of a manufacturing plant.

CLAIMS

1. Apparatus for measuring the thickness of a non-magnetic coating and a magnetically susceptible substrate comprising, in combination;

   an ultrasonic transmitter and receiver and timing means arranged to ascertain the transit time of an ultrasonic pulse through the coating and substrate;

   a magnet one pole of which faces the coating surface;

   a magnetic field sensor between the pole of the magnet and the coating surface; and

   a processor arranged to ascertain from at least the output of the magnetic field sensor the coating thickness and from this and from the transit time of the ultrasonic pulse the thickness of the substrate.

2. Apparatus according to claim 1 wherein the magnetic sensor is physically attached to the pole of the magnet.

3. Apparatus according to claim 1 or claim 2 wherein the magnetic field sensor is a Hall effect device.

4. Apparatus according to claim 3 further comprising a linearizing means for linearizing the output of the Hall effect device.

5. Apparatus according to claim 4 wherein the linearizing means comprises a look up table.

6. Apparatus according to claim 4 wherein the linearizing means comprises a mathematical model.

7. Apparatus according to claim 4 wherein the mathematical model is a polynomial approximation.

8. Apparatus according to any preceding claim wherein the thickness of the magnet is greater than 6mm.

9. Apparatus according to any preceding claim wherein the thickness of the magnet is greater than 10mm.

10. Apparatus according to any preceding claim wherein the thickness of the magnet is greater than 22mm.

11. Apparatus according to any preceding claim wherein the transmitter and receiver are distinct items.

12. Apparatus according to any preceding claim comprising means for displaying both calculated thicknesses.

13. Apparatus substantially as herein described with reference to and/or as illustrated in the accompanying drawings.

The Patent Office

10

Application No:	GB 9618261.3	**Examiner:**	Mr A Oldershaw
Claims searched:	1 to 13	**Date of search:**	13 November 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N NCTA, NCTG

Int Cl (Ed.6): G01B

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US5418823 (KERVINEN)	
X	US5329561 (DESRUELLES)	1 at least
X	US5225148 (DESRUELLES)	1 at least
A	US5062298 (FALCOFF)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
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